
**Gas cylinders — Refillable seamless steel
gas cylinders — Design, construction and
testing**

Part 2:

**Quenched and tempered steel cylinders
with tensile strength greater than or equal
to 1 100 MPa**

*Bouteilles à gaz — Bouteilles à gaz rechargeables en acier sans
soudure — Conception, construction et essais —*

*Partie 2: Bouteilles en acier trempé et revenu ayant une résistance à la
traction supérieure ou égale à 1 100 MPa*



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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 9809 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 9809-2 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

ISO 9809 consists of the following parts, under the general title *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing*:

- *Part 1: Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa*
- *Part 2: Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa*
- *Part 3: Normalized steel cylinders*

Annex B forms a normative part of this part of ISO 9809. Annexes A, C and D are for information only.

Introduction

The purpose of this part of ISO 9809 is to provide a specification for the design, manufacture, inspection and testing of a seamless steel cylinder for worldwide usage. The objective is to balance design and economic efficiency against international acceptance and universal utility.

This part of ISO 9809 aims to eliminate the concern about climate, duplicate inspections and restrictions currently existing because of lack of definitive International Standards. This part of ISO 9809 should not be construed as reflecting on the suitability of the practice of any nation or region.

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Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing —

Part 2:

Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa

1 Scope

This part of ISO 9809 specifies minimum requirements for the material, design, construction and workmanship, manufacturing processes, and tests at manufacture of refillable quenched and tempered seamless steel gas cylinders of water capacities from 0,5 l up to and including 150 l for compressed, liquefied and dissolved gases exposed to extreme world wide ambient temperatures (normally between $-50\text{ }^{\circ}\text{C}$ and $+65\text{ }^{\circ}\text{C}$). This part of ISO 9809 is applicable to cylinders with a maximum tensile strength R_m of greater than or equal to 1 100 MPa. It does not cover cylinders with $R_{m\text{max.}} > 1\,300\text{ MPa}$ for diameters $> 140\text{ mm}$ and guaranteed wall thicknesses (a') $\geq 12\text{ mm}$, and $R_{m\text{max.}} \geq 1\,400\text{ MPa}$ for diameters $\leq 140\text{ mm}$ and guaranteed wall thicknesses (a') $\geq 6\text{ mm}$, because beyond these limits additional requirements may apply.

NOTE 1 If so desired, cylinders of water capacity less than 0,5 l may be manufactured and certified to this part of ISO 9809.

NOTE 2 For quenched and tempered cylinders with maximum tensile strength less than 1 100 MPa refer to ISO 9809-1. For normalized steel cylinders refer to ISO 9809-3.

NOTE 3 Grades and strength ranges of steels used for these types of cylinders may not be compatible with some gas services (see 6.1.4) and operational conditions.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 9809. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 9809 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 148:1983¹⁾, *Steel — Charpy impact test (V-notch)*.

ISO 2604-2:1975, *Steel products for pressure purposes — Quality requirements — Part 2: Wrought seamless tubes*.

ISO 6506:1981²⁾, *Metallic materials — Hardness test — Brinell test*.

ISO 6508:1986³⁾, *Metallic materials — Hardness test — Rockwell test (scales A-B-C-D-E-F-G-H-K)*.

ISO 6892:1998, *Metallic materials — Tensile testing at ambient temperature*.

¹⁾ To be replaced by ISO 148-1 (in preparation), ISO 148-2:1998 and ISO 148-3:1998.

²⁾ Replaced by ISO 6506-1:1999, ISO 6506-2:1999 and ISO 6506-3:1999.

³⁾ Replaced by ISO 6508-1:1999, ISO 6508-2:1999 and ISO 6508-3:1999.

ISO 7438:1985, *Metallic materials — Bend test*.

ISO 9712:1999, *Non-destructive testing — Qualification and certification of personnel*.

ISO 11114-1:1997, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials*.

ISO 13769⁴⁾, *Gas cylinders — Stamp marking*.

3 Terms and definitions

For the purposes of this part of ISO 9809 the following terms and definitions apply.

3.1 yield stress

value corresponding to the upper yield stress, R_{eH} or, for steels that do not exhibit a defined yield, the 0,2 % proof stress (non-proportional elongation), $R_{p0,2}$

[ISO 6892]

3.2 quenching

hardening heat treatment in which a cylinder, which has been heated to a uniform temperature above the upper critical point Ac_3 of the steel, is cooled rapidly in a suitable medium

3.3 tempering

softening heat treatment which follows quenching, in which the cylinder is heated to a uniform temperature below the lower critical point Ac_1 of the steel

3.4 batch

quantity of up to 200 cylinders plus cylinders for destructive testing of the same nominal diameter, thickness and design made successively from the same steel and subjected to the same heat treatment for the same duration of time.

NOTE The lengths of the cylinders in a batch may vary by ± 12 %.

3.5 test pressure

p_h
required pressure applied during a pressure test

NOTE It is used for cylinder wall thickness calculation.

3.6 burst pressure

highest pressure reached in a cylinder during a burst test

3.7 design stress factor

F
ratio of equivalent wall stress at test pressure (p_h) to the guaranteed minimum yield stress (R_e)

⁴⁾ To be published.

4 Symbols

Table 1 lists the symbols and their designations

Table 1 — Symbols and designations

Symbol	Designation
a	Calculated minimum thickness, in millimetres, of the cylindrical shell
a'	Guaranteed minimum thickness, in millimetres, of the cylindrical shell
a_1	Guaranteed minimum thickness, in millimetres, of a concave base at the knuckle (see Figure 2)
a_2	Guaranteed minimum thickness, in millimetres, at the centre of a concave base (see Figure 2)
A	Percentage elongation
b	Guaranteed minimum thickness, in millimetres, at the centre of a convex base (see Figure 1)
c	Maximum permissible deviation of burst profile, in millimetres (see Figure 13)
d	Depth of artificial flaw, in millimetres, in flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)
D	Nominal outside diameter of the cylinder, in millimetres (see Figure 1)
D_c	External diameter, in millimetres, of cutter milling tool for flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)
D_f	Diameter, in millimetres, of former (see Figure 8)
F	Design stress factor (variable) (see 3.7)
h	Outside depth (concave base end), in millimetres (see Figure 2)
H	Outside height, in millimetres, of domed part (convex head or base end) (see Figure 1)
l_o	Length of artificial flaw, in millimetres, in flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)
l	Length of cylindrical part of the cylinder, in millimetres (see Figure 3)
L_o	Original gauge length, in millimetres, as defined in ISO 6892 (see Figure 7)
p_b	Measured burst pressure, in bar ^a , above atmospheric pressure
p_f	Measured failure pressure, in bar ^a , above atmospheric pressure
p_H	Hydraulic test pressure, in bar ^a , above atmospheric pressure
p_s^b	Calculated design working pressure, in bar ^a , above atmospheric pressure
p_y	Observed pressure when cylinder starts yielding during hydraulic bursting test, in bar ^a , above atmospheric pressure
r	Inside knuckle radius, in millimetres (see Figure 1 and Figure 2)
r_c	Cutter tip radius of milling tool for artificial flaw, in millimetres, for flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)
R_e	Minimum guaranteed value of yield stress (see 3.1), in MPa
R_{ea}	Actual value of the yield stress, in MPa, as determined by the tensile test (see 10.2)

Table 1 (continued)

Symbol	Designation
R_g	Minimum guaranteed value of tensile strength, in MPa
R_m	Actual value of tensile strength, in MPa, as determined by the tensile test (see 10.2)
R_m max.	Maximum actual value of the tensile strength range, in MPa
R_m min.	Minimum actual value of the tensile strength range, in MPa
S_0	Original cross-sectional area of tensile test piece, in square millimetres, in accordance with ISO 6892
t	Actual thickness of the test specimen, in millimetres
V	Water capacity of cylinder, in litres
w	Width, in millimetres, of the tensile test piece (see Figure 7)
^a 1 bar = 10^5 Pa = 0,1 MPa ^b p_s is equal to $2/3 p_h$	

5 Inspection and testing

Evaluation of conformity is required to be performed in accordance with the relevant regulations of the country(ies) where the cylinders are used.

In order to ensure that the cylinders are in compliance with this international standard they shall be subject to inspection in accordance with clauses 9, 10 and 11 by an authorized inspection authority (hereafter referred to as "the inspector") recognized in the countries of use. The inspector shall be competent for inspection of cylinders.

6 Materials

6.1 General requirements

6.1.1 Materials for the manufacture of gas cylinders intended for international service shall fall within one of the following categories:

- a) internationally recognized cylinder steels;
- b) nationally recognized cylinder steels;
- c) new cylinder steels resulting from technical progress.

For all categories, the relevant conditions specified in 6.2 and 6.3 shall be satisfied.

6.1.2 The material used for the fabrication of gas cylinders shall be steel, other than rimming quality, with non-ageing properties, and shall be aluminium and/or silicon killed.

In cases where examination of this non-ageing property is required by the customer, the criteria by which it is to be specified shall be agreed with the customer and inserted into the order.

6.1.3 The cylinder manufacturer shall establish means to identify the cylinders with the cast of steel from which they are made.

6.1.4 High strength steels used for manufacture of high strength cylinders are normally not compatible with corrosive or embrittling gases (see ISO 11114-1). They may nevertheless be used with these gases provided that their compatibility is proven by a recognized test method.

6.2 Controls on chemical composition

6.2.1 The chemical composition of all steels shall be defined at least by:

- the carbon, manganese and silicon contents in all cases;
- the chromium, nickel and molybdenum contents or other alloying elements intentionally added to the steel;
- the maximum sulphur and phosphorus contents in all cases.

The carbon, manganese and silicon contents and, where appropriate, the chromium, nickel and molybdenum contents shall be given, with tolerances, such that the differences between the maximum and minimum values of the cast do not exceed the values shown in Table 2.

Table 2 — Chemical composition tolerances

Element	Maximum content (m/m)	Permissible range (m/m)
Carbon	< 0,30 %	0,03 %
	≥ 0,30 %	0,04 %
Manganese	All values	0,20 %
Silicon	All values	0,15 %
Chromium	< 1,20 %	0,20 %
	≥ 1,20 %	0,30 %
Nickel	All values	0,30 %
Molybdenum	< 0,50 %	0,10 %
	≥ 0,50 %	0,15 %

The combined content of the following elements: vanadium, niobium, titanium, boron and zirconium, shall not exceed 0,15 %.

The actual content of any element deliberately added shall be reported and its maximum content shall be representative of good steel-making practice.

6.2.2 Sulphur and phosphorus in the cast analysis of material used for the manufacture of gas cylinders shall not exceed the values shown in Table 3.

Table 3 — Maximum sulphur and phosphorus limits

Sulphur	0,010 % (m/m)
Phosphorus	0,015 % (m/m)
Sulphur + phosphorus	0,020 % (m/m)

6.2.3 The cylinder manufacturer shall obtain and provide certificates of cast (heat) analyses of the steels supplied for the construction of gas cylinders.

Should check analyses be required, they shall be carried out either on specimens taken during manufacture from the material in the form as supplied by the steelmaker to the cylinder manufacturer, or from finished cylinders. In any check analysis, the maximum permissible deviation from the limits specified for the cast analyses shall conform to the values specified in ISO 2604-2.

6.3 Heat treatment

6.3.1 The cylinder manufacturer shall certify the heat treatment process applied to the finished cylinders.

6.3.2 Quenching in media other than mineral oil is permissible provided that the method produces cylinders free of cracks.

If the average rate of cooling in the medium is greater than 80 % of that in water at 20 °C without additives, every production cylinder shall be subjected to a method of non-destructive testing to prove freedom from cracks.

6.3.3 The tempering process shall achieve the required mechanical properties.

The actual temperature to which a type of steel is subjected for a given tensile strength shall not deviate by more than 30 °C from the temperature specified by the cylinder manufacturer.

6.4 Testing requirements

The material of the finished cylinders shall satisfy the requirements of clauses 9, 10 and 11.

6.5 Failure to meet test requirements

In the event of failure to meet test requirements, retesting or reheat treatment and retesting shall be carried out as follows to the satisfaction of the inspector:

- a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored.
- b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.
 - 1) If the failure is considered to be due to the applied heat treatment, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment i.e. if the failure is in a test representing the prototype or batch cylinders, test failure shall require reheat treatment of all the represented cylinders prior to re-testing; however, if the failure occurs sporadically in a test applied to every cylinder, then only those cylinders which fail the test shall require re-heat treatment and re-testing.

This reheat treatment shall consist of retempering or requenching and tempering.

Whenever cylinders are reheat treated, the minimum guaranteed wall thickness shall be maintained.

Only the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected.

- 2) If the failure is due to a cause other than the applied heat treatment, all defective cylinders shall be either rejected, or repaired by an approved method. Provided that the repaired cylinders pass the test(s) required for the repair, they shall be reinstated as part of the original batch.

7 Design

7.1 General requirements

7.1.1 The calculation of the wall thickness of the pressure-containing parts shall be related to the guaranteed minimum yield stress R_e of the material.

7.1.2 For calculation purposes, the value of R_e shall not exceed $0,9 R_g$.

7.1.3 The internal pressure upon which the calculation of wall thickness is based shall be the hydraulic test pressure p_h .

7.2 Limitation on tensile strength

The maximum value of the tensile strength is limited by the ability of the steel to pass the requirements of clause 9 and clause 10. The maximum range of tensile strength shall be 120 MPa (i.e. $R_m \text{ max.} - R_m \text{ min.} \leq 120 \text{ MPa}$).

However, the actual value of the tensile strength as determined in 10.2 shall not exceed 1 300 MPa for cylinders with outside diameter $> 140 \text{ mm}$, and 1 400 MPa for cylinders with outside diameter $\leq 140 \text{ mm}$.

7.3 Calculation of cylindrical shell thickness

The guaranteed minimum thickness of the cylindrical shell (a') shall be not less than the thickness calculated using equations (1) and (2), and in addition condition (3) shall be satisfied.

$$a \geq \frac{D}{2} \left(1 - \sqrt{\frac{10FR_e - \sqrt{3} p_h}{10FR_e}} \right) \quad (1)$$

where the value of F is the lesser of $\frac{0,65}{R_e/R_g}$ or 0,77.

R_e/R_g shall not exceed 0,9.

The wall thickness shall also satisfy the formula

$$a \geq \frac{D}{250} + 1 \quad (2)$$

with an absolute minimum of $a = 1,5 \text{ mm}$.

The burst ratio

$$p_b/p_h \geq 1,6 \quad (3)$$

shall be satisfied by test.

NOTE 1 If the result of these requirements is a guaranteed thickness of the cylindrical shell (a') $\geq 12 \text{ mm}$ for diameter $D > 140 \text{ mm}$, or a guaranteed thickness of the cylindrical shell $a' \geq 6 \text{ mm}$ for diameter $D \leq 140 \text{ mm}$, then such a design would be outside the scope of this part of ISO 9809.

NOTE 2 It is generally assumed that $p_h = 1,5 \times p_s$ for permanent gases for cylinders designed and manufactured to this part of ISO 9809.

7.4 Calculation of convex ends (heads and bases)

7.4.1 The thickness, b , at the centre of a convex end shall be not less than that required by the following criteria.

Where the inside knuckle radius, r , is not less than $0,075 D$, then

$$b \geq 1,5 a \text{ for } 0,40 > H/D \geq 0,20$$

$$b \geq a \text{ for } H/D \geq 0,40$$

In order to obtain a satisfactory stress distribution in the region where the end joins the shell, any thickening of the end that may be required shall be gradual from the point of juncture, particularly at the base. For the application of this rule the point of juncture between the shell and the end is defined by the horizontal line indicating dimension H in Figure 1.

7.4.2 The cylinder manufacturer shall prove by the pressure cycling test detailed in 9.2.4 that the design is satisfactory.

The shapes shown in Figure 1 are typical of convex heads and base ends. Shapes A, C and D are base ends and shape B is a head.

7.5 Calculation of concave base ends

When concave base ends (see Figure 2) are used the following design values are recommended:

$$a_1 \geq 2a$$

$$a_2 \geq 2a$$

$$h \geq 0,12 D$$

$$r \geq 0,075 D$$

The design drawing shall at least show values for a_1 , a_2 , h and r .

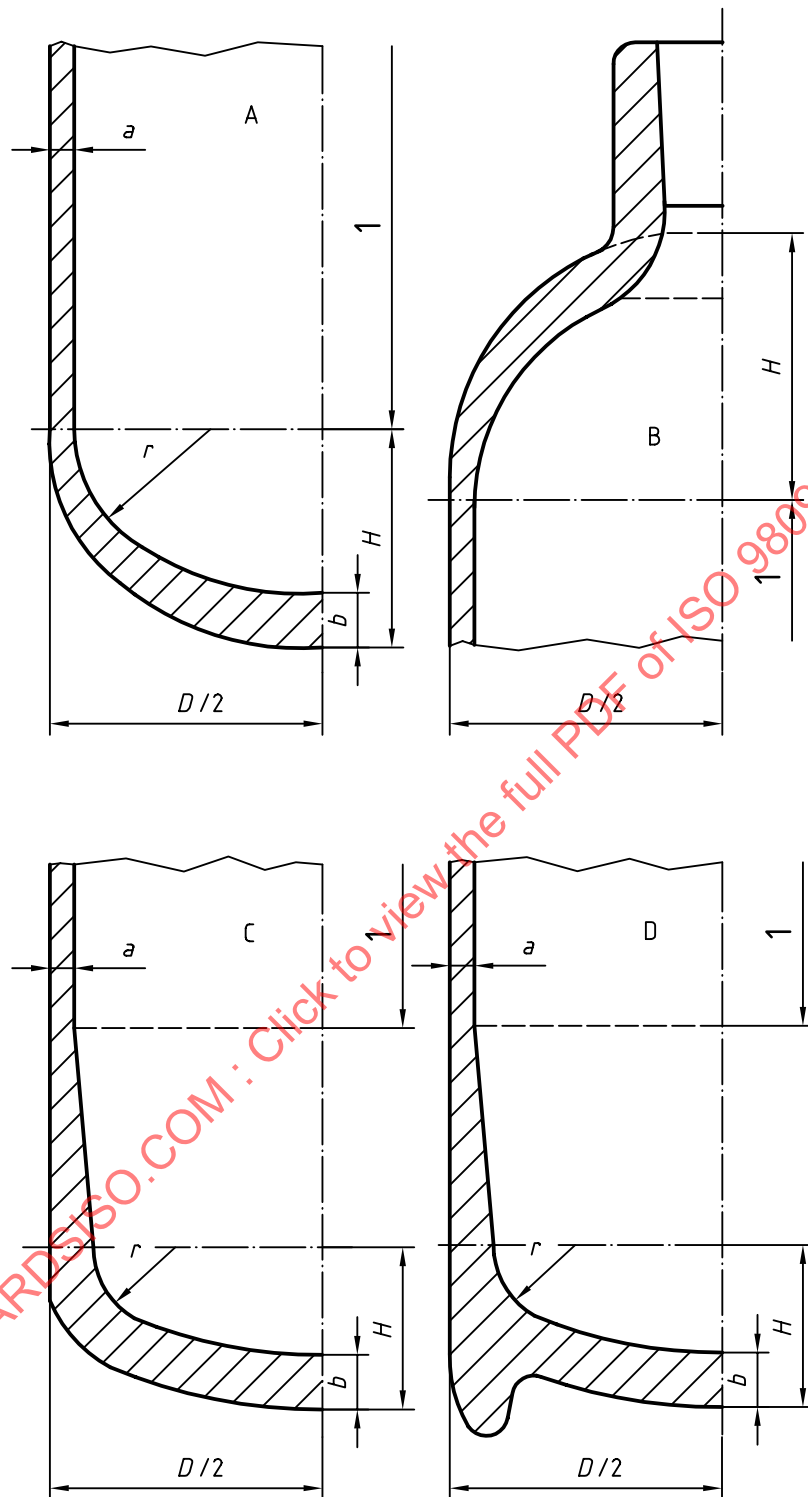
In order that a satisfactory stress distribution be obtainable, the thickness of the cylinder shall increase progressively in the transition region between the cylindrical part and the base.

The cylinder manufacturer shall in any case prove by the pressure cycling test detailed in 9.2.4 that the design is satisfactory.

7.6 Neck design

7.6.1 The external diameter and thickness of the formed neck end of the cylinder shall be adequate for the torque applied in fitting the valve to the cylinder. The torque may vary according to the diameter of thread, the form of thread and the sealant used in the fitting of the valve. (Guidance on torques is given in ISO 13341.)

7.6.2 In establishing the minimum thickness, consideration shall be given to obtaining a wall thickness in the cylinder neck which will prevent permanent expansion of the neck during the initial and subsequent fittings of the valve into the cylinder without support of an attachment such as a neck ring.

**Key**

1 Cylindrical part

Figure 1 — Typical convex ends

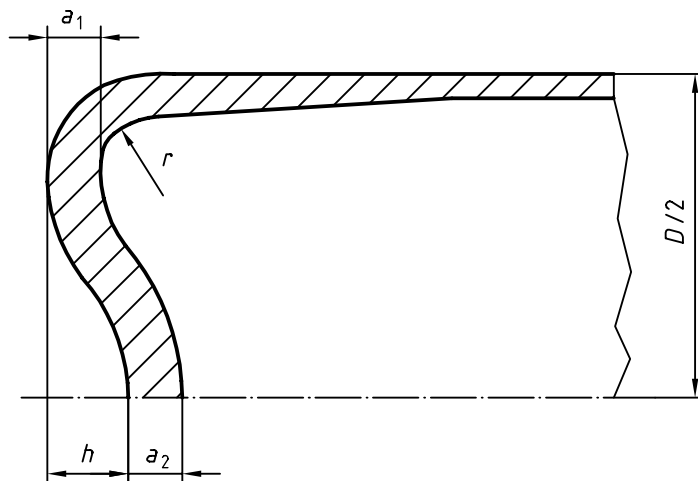


Figure 2 — Concave base ends

7.7 Foot-rings

When a foot-ring is provided, it shall be sufficiently strong and made of material compatible with that of the cylinder. The shape should preferably be cylindrical and shall give the cylinder sufficient stability. The foot-ring shall be secured to the cylinder by a method other than welding, brazing or soldering. Any gaps which may form water traps shall be sealed by a method other than welding, brazing or soldering. This is particularly important in the case of high-strength cylinders.

7.8 Neck-rings

When a neck-ring is provided, it shall be sufficiently strong and made of material compatible with that of the cylinder and shall be securely attached by a method other than welding, brazing or soldering.

The manufacturer shall ensure that the axial load to remove the neck-ring is greater than 10 times the weight of the empty cylinder and not less than 1 000 N, and that the torque to turn the neck ring is greater than 100 N·m.

7.9 Design drawing

A fully dimensioned drawing shall be prepared which includes the specification of the material.

8 Construction and workmanship

8.1 General

The cylinder shall be produced by

- a) forging or drop forging from a solid ingot or billet or
- b) manufacturing from seamless tube or
- c) pressing from a flat plate.

Cylinders may be designed with one or two openings along the central cylinder axis. Metal shall not be added in the process of closure of the end. Plugging to correct manufacturing defects in bases is not permitted.

8.2 Wall thickness

During production each cylinder or semi-finished shell shall be examined for thickness. The wall thickness at any point shall be not less than the minimum thickness specified.

8.3 Surface defects

The internal and external surfaces of the finished cylinder shall be free from defects which would adversely affect the safe working of the cylinder. See annex A for examples of defects and guidance on their evaluation.

8.4 Ultrasonic examination

For small cylinders with a cylindrical length of less than 200 mm or where the product of $p_s \cdot V < 800$, ultrasonic examination is not necessary.

All other finished cylinders, at the end of manufacture, shall be ultrasonically examined for defects in accordance with annex B. This test does not necessarily cover the tests required in 6.3.2.

8.5 Out-of-roundness

The out-of-roundness of the cylindrical shell, i.e. the difference between the maximum and minimum outside diameters at the same cross-section shall not exceed 2 % of the mean of these diameters.

8.6 Mean diameter

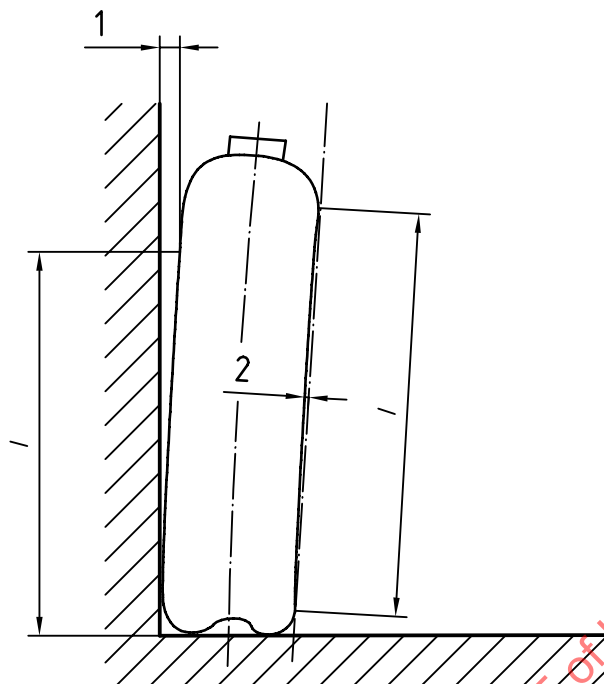
The mean external diameter of the cylindrical part outside the transition zones on a cross section shall not deviate more than ± 1 % from the nominal design diameter.

8.7 Straightness

The maximum deviation of the cylindrical part of the shell from a straight line shall not exceed 3 mm per metre length (see Figure 3).

8.8 Verticality

Deviation from vertical shall not exceed 10 mm per metre length (see Figure 3).



Key

- 1 Maximum 0,01 l (see 8.8)
- 2 Maximum 0,003 l (see 8.7)

Figure 3 — Illustration of deviation of cylindrical part of shell from a straight line and from vertical

9 Type approval procedure

9.1 General requirements

A technical specification of each new design of cylinder [or cylinder family as defined in f) below] including design drawing, design calculations, steel details and heat treatment, shall be submitted by the manufacturer to the inspector. The type approval tests detailed in 9.2 shall be carried out on each new design under the supervision of the inspector.

A cylinder shall be considered to be of a new design, compared with an existing approved design, when:

- a) it is manufactured in a different factory or
- b) it is manufactured by a different process (see 8.1) or
- c) it is manufactured from a steel of different specified chemical composition range as defined in 6.2.1 or
- d) it is given a different heat treatment beyond the limits stipulated in 6.3 or
- e) the base or the base profile has changed, e.g. concave, convex, hemispherical or also if there is a change in base thickness/cylinder diameter ratio or
- f) the overall length of the cylinder has increased by more than 50 % (cylinders with a length/diameter ratio less than 3 shall not be used as reference cylinders for any new design with this ratio greater than 3) or
- g) the nominal outside diameter has changed or
- h) the design wall thickness has changed or

- i) the hydraulic test pressure has been increased (where a cylinder is to be used for lower-pressure duty than that for which design approval has been given, it shall not be deemed to be a new design) or
- j) the guaranteed minimum yield stress (R_e) and/or the guaranteed minimum tensile strength (R_g) have changed.

9.2 Prototype tests

9.2.1 A minimum of 50 cylinders which are guaranteed by the manufacturer to be representative of the new design shall be made available for prototype testing. However, if, for special applications, the total number of cylinders required is less than 50, enough cylinders shall be made to complete the prototype tests required, in addition to the production quantity.

9.2.2 In the course of the type approval process, the inspector shall select the necessary cylinders for testing and

a) verify that:

- the design conforms to the requirements of clause 7;
- the thicknesses of the walls and ends on two cylinders (those taken for mechanical testing) meet the requirements of 7.3 to 7.6, the measurements being taken at least at three transverse sections of the cylindrical part and on a longitudinal section of the base and head;
- the requirements of clause 6 (Materials) are complied with;
- the requirements of 7.7, 7.8 and 8.5 to 8.8 inclusive are complied with for all cylinders selected by the inspector;
- the internal and external surfaces of the cylinders are free of any defect which might make them unsafe to use (for examples see annex A).

b) supervise the following tests on the cylinders selected:

- the tests specified in 10.1.2 a) (hydraulic burst test) on 2 cylinders, the cylinders bearing representative stampmarkings;
- the tests specified in 10.1.2 b) (mechanical testing) on 2 cylinders, the test pieces being identifiable with the batch. Prior to sectioning the test cylinders, hardness tests on the complete cylinders shall be carried out on the production line hardness testing machine at the spot where the tensile test pieces are taken to verify the hardness/tensile correlation (see 9.2.3);
- a hardness survey, comprising of four hardness tests at 90° to each other at each end of the cylindrical wall, on the two cylinders selected for mechanical testing. The maximum range of Brinell hardness on each cylinder shall be 25 HB; the manufacturer shall establish the equivalent range to this when an alternative hardness testing method is used;
- the tests specified in 9.2.4 (pressure cycling test) on 2 cylinders, the cylinders bearing representative stampmarkings;
- the tests specified in 9.2.5 (flawed cylinder burst test) on at least 2 cylinders;
- the tests specified in 9.2.6 (flawed cylinder cycle test) on 2 cylinders;
- for cylinders made from seamless tube, the test specified in 9.2.7 (base check) on the 2 cylinders selected for mechanical testing.

NOTE Consideration should be given to selecting cylinders which represent the lower and upper values of the hardness range within the batch.

9.2.3 Verification of hardness/tensile correlation

The manufacturer shall demonstrate, to the satisfaction of the inspector, that the hardness range specified is related to the tensile range specified in 7.2. When Brinell hardness testing is used, the following procedure shall be adopted.

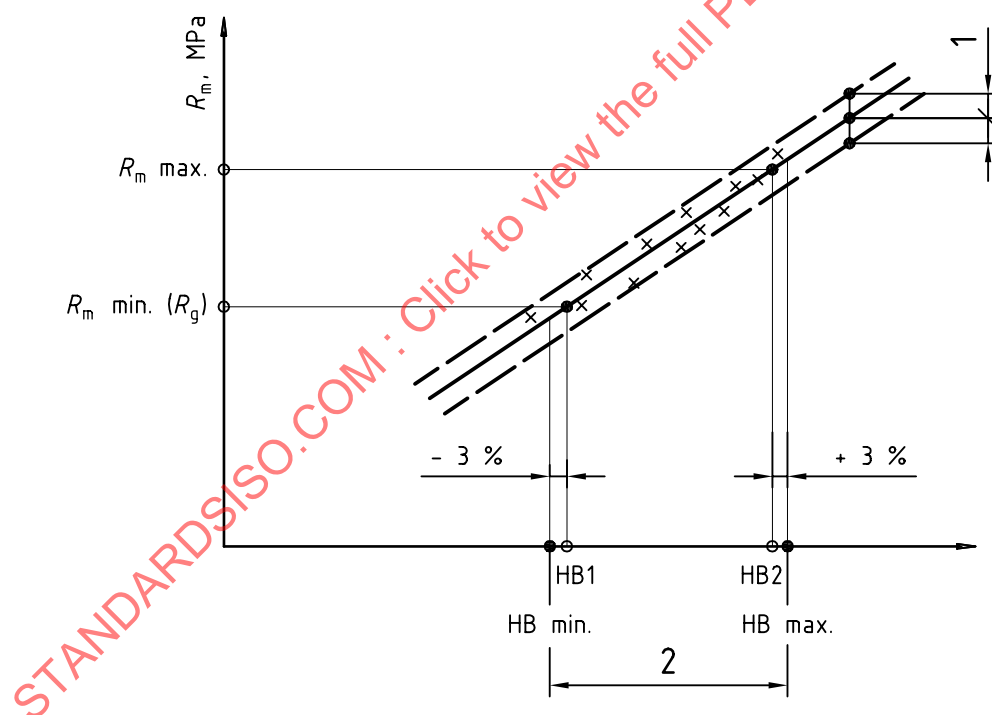
Prior to the presentation of a first batch of cylinders for prototype testing the manufacturer shall establish a linear regression between R_m and HB for the type of steel, and heat treatment method used, using a minimum of 20 values of R_m and HB tested on 10 cylinders at each end. The hardness values shall be obtained on complete cylinders tested on the production line hardness testing machine; the tensile test pieces shall be taken at the hardness test spot. The values obtained shall cover the anticipated tensile range.

In order to determine the limits for the hardness range as required in 11.3, a scatter of 3 % around HB1 and HB2 shall be permitted (to allow for example for machine dispersion and operator dispersion). The guaranteed hardness range shall be therefore:

$$\text{HB min.} = \text{HB1} - 3 \%$$

$$\text{HB max.} = \text{HB2} + 3 \%$$

but the maximum hardness range $\text{HB max.} - \text{HB min.}$ shall not exceed 55 HB (equivalent to $\leq 200 \text{ MPa}$). (See Figure 4.)



Key

- 1 Scatterband, max $\pm 25 \text{ MPa}$
- 2 Hardness range

Figure 4 — Hardness/tensile test graph

At the prototype stage hardness tests shall be taken as described in 9.2.2 b) at the spot where the tensile test specimen is taken. The results of hardness and tensile strength shall be compared with the graph established by the manufacturer to determine whether they are within the scatterband (see Figure 4). When hardness measurements are outside the limits as stated above, see 6.5.

NOTE An equivalent test procedure may be used provided equivalence of the scatterband and of the maximum hardness range can be demonstrated.

9.2.4 Pressure cycling test

This test shall be carried out with a non-corrosive liquid subjecting the cylinders to successive reversals at an upper cyclic pressure which is at least equal to the hydraulic test pressure (p_h). The cylinders shall withstand 12 000 cycles without failure.

For cylinders with hydraulic test pressure (p_h) > 450 bar, the upper cyclic pressure may be reduced to two-thirds of this test pressure. In this case the cylinders shall withstand 80 000 cycles without failure.

The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure, but shall have an absolute maximum of 30 bar.

The frequency of reversals of pressure shall not exceed 0,25 Hz (15 cycles/min.). The cylinder shall actually experience the maximum and minimum cyclic pressures during the test. The temperature measured on the outside surface of the cylinder shall not exceed 50 °C during the test.

After the test the cylinder bases shall be sectioned in order to measure the thickness and to ensure that this thickness is sufficiently close to the minimum thickness prescribed in the design and shall be within the usual production tolerances. In no case shall the actual base thickness exceed that specified on the drawing by more than 15 %.

The test shall be considered satisfactory if the cylinder attains the required number of cycles without developing a leak.

9.2.5 Flawed cylinder burst test

9.2.5.1 General

The flawed cylinder burst test shall be carried out to determine if the failure pressure (p_f) which produces the leak (and not a burst) with a flaw of a given size is greater than the design working pressure (p_s) of the cylinder, adjusted for the actual thickness versus calculated minimum wall thickness, where:

$$p_s = 2/3 p_h$$

9.2.5.2 Details of flaw

See Figure 5.

The flaw shall be machined longitudinally, approximately at mid-length of the cylindrical part of the cylinder. The flaw shall be located at the point of minimum wall thickness (t) of the mid-section, based on thickness measurement at four points around the cylinder.

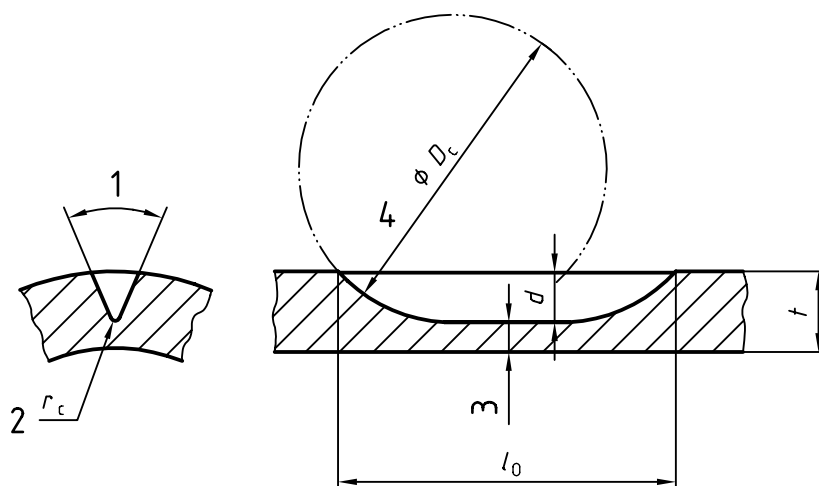
The flaw length l_o shall be the overall length of cut and shall have the value:

$$l_o = 1,6 \sqrt{D a}$$

The flaw cutter shall be approximately 12,5 mm thick with an angle of 45° and a tip radius r_c of 0,25 mm ± 0,025 mm. The cutter diameter (D_c) shall be 50 mm for cylinders with a diameter $D \leq 140$ mm, and 65 mm to 80 mm for cylinders with $D > 140$ mm. A standard Charpy V-notch (CVN) cutter is recommended.

NOTE The cutter should be sharpened regularly to ensure the tip radius meets requirements.

The depth, d , of the flaw shall be adjusted to obtain a leak by hydropressurization. "Leak" means that the crack has not propagated by more than 10 % outside the machined flaw length, as measured on the external surface, i.e. total length shall be not greater than $1,1 \times l_o$.



Key

- 1 45° cutter angle
- 2 Cutter profile radius, r_c
- 3 Ligament
- 4 Cutter diameter D_c

Figure 5 — Profile of artificial flaw

9.2.5.3 Test procedure

The test shall be performed by monotonic pressurization or cyclic pressurization as described below:

9.2.5.3.1 Monotonic pressurization

The cylinder shall be pressurized hydrostatically as described in 10.5 (hydraulic bursting test) until pressure is released from the cylinder at the flaw location.

9.2.5.3.2 Cyclic pressurization

The test shall be performed as described in 9.2.4 (pressure cycling test) with the upper cyclic pressure being the calculated design working pressure of the cylinder adjusted for actual thickness versus calculated minimum wall thickness (i.e. $p_s \times t/a$).

9.2.5.4 Acceptance criteria for the flawed cylinder burst test

The cylinder shall have passed the test if the following conditions are met.

a) For cylinders tested using monotonic pressurization:

- the failure pressure (p_f) shall be equal to or greater than the calculated design working pressure ($p_s = 2/3 \times p_n$) of the cylinder adjusted for the actual thickness versus calculated minimum wall thickness, and the failure mode shall be by a "leak", i.e. $p_f/p_s \geq 1,0 t/a$.

If these requirements are not fulfilled (i.e. failure occurs below $p_s \times 1,0 t/a$) but the failure mode is a leak, then a new test may be performed with a shallower flaw. Also if burst type failure occurs at a pressure greater than $p_s \times 1,0 t/a$ but the flaw depth is shallow, a new test may be performed with a deeper flaw.

- a total crack length measured on the external surface of 1,1 times the original machined length is allowed, i.e. total crack length shall not be greater than $1,1 l_0$.

b) For cylinders tested using cyclic pressurization:

- fatigue crack growth beyond the original machined flaw length is allowed. However, the failure mode shall be by a “leak”.

9.2.6 Flawed cylinder cycle test

9.2.6.1 Test conditions

The flawed cylinder cycle test shall be carried out as described in 9.2.4 with the exception that the cycling frequency shall not exceed 5 cycles per minute.

The cylinders shall contain an artificial flaw as described in 9.2.6.2.

9.2.6.2 Details of flaw

See Figure 5.

The flaw shall be machined longitudinally, approximately at mid-length of the cylindrical part of the cylinder. The flaw shall be located at minimum wall thickness, t , of the mid-section.

The flaw length l_0 shall be the overall length of cut and shall have the value:

$$l_0 = 1,6 \sqrt{D a}$$

The flaw cutter shall be approximately 12,5 mm thick with an angle of 45° and a tip radius r_c of 0,25 mm ± 0,025 mm. The cutter diameter (D_c) shall be 50 mm for cylinders with a diameter D less than or equal to 140 mm, and 65 mm to 80 mm for cylinders with D greater than 140 mm. A standard CVN cutter is recommended.

NOTE 1 The cutter should be sharpened regularly to ensure the tip radius meets requirements.

The depth, d of the flaw shall be not less than 10 % of the wall thickness, t .

When measuring the actual flaw depth a deviation not exceeding 0,1 mm is acceptable (e.g. for an actual wall thickness of 7 mm the flaw depth shall in no case be less than 0,6 mm).

9.2.6.3 Acceptance criteria for the flawed cylinder cycle test

The cylinder shall have passed the test if the number of cycles attained without failure exceeds 3 500 as a mean value of the two cylinders tested but with an absolute minimum of 3 000.

The test report shall include actual details of the test as follows, in addition to cylinder design details:

- pressure range;
- cycle rate;
- temperature range;
- actual flaw length;
- actual wall thickness;
- actual flaw depth;
- number of cycles obtained without failure.

If the test is continued to failure, then the mode of failure shall be reported (i.e. leak or burst).

If the cylinders pass a minimum of 12 000 cycles without failure, then the unflawed pressure cycling test as required in 9.2.2 b) and specified in 9.2.4 need not be carried out.

9.2.7 Base check (for cylinders made from tube only)

A meridian section shall be made in the base of the cylinder and one of the surfaces thus obtained polished for examination under a magnification of between $\times 5$ and $\times 10$.

The cylinder shall be regarded as defective if the presence of cracks is detected. It shall also be regarded as defective if the dimensions of any pores or inclusions present reach values considered to pose a threat to safety.

In no case shall the sound thickness (i.e. the thickness with no defects) in the base centre be less than the minimum specified thickness (see 7.4.1).

9.3 Type approval certificate

If the results of the checks according to 9.2 are satisfactory, the inspector shall issue a type approval certificate, a typical example of which is given in annex C.

10 Batch tests

10.1 General requirements

10.1.1 All tests for checking the quality of the gas cylinder shall be carried out on material from finished cylinders. Each cast of steel shall be represented by a set of batch tests (for the definition of a batch see 3.4).

For the purpose of batch testing, the manufacturer shall provide the inspector with:

- the type approval certificate;
- the certificates stating the cast analysis of the steel supplied for the manufacture of the cylinders;
- evidence that appropriate heat treatment has been performed;
- certificates showing the ultrasonic testing results;
- a list of the cylinders, stating serial numbers and stamp markings as required;
- confirmation that threads have been checked properly in accordance with gauging requirements. The gauges to be used shall be specified (e.g. ISO 11191).

10.1.2 During batch testing, the inspector shall

- ascertain that the type approval certificate has been obtained and the cylinders conform to it;
- check that the requirements set out in clauses 6, 7 and 8 have been met and in particular check by an external and, if physically possible, internal visual examination of the cylinders whether their construction and the checks carried out by the manufacturer in accordance with 7.7, 7.8 and 8.2 to 8.8 are satisfactory. The visual examination shall cover at least 10 % of the cylinders submitted. However, if an unacceptable defect is found (for examples see annex A), 100 % of the cylinders shall be visually inspected;
- select the necessary cylinders per batch for destructive testing and supervise the tests specified in 10.1.2 a) (hydraulic burst tests) and 10.1.2 b) (mechanical testing). Where alternative tests are permitted, the purchaser and manufacturer shall agree which tests are to be carried out;
- supervise the test specified in 9.2.5 (flawed cylinder burst test) on 1 cylinder when the Charpy values do not meet the B-values in Table 4 (see 10.4.2);

- supervise the test specified in 9.2.5 (flawed cylinder burst test) on 2 cylinders when the Charpy values are less than 80 % of the approved Charpy values (i.e. those obtained during the type approval), and the approved Charpy values are higher than the B-values in Table 4 (see 10.4.2). If the flawed cylinder burst test is then satisfied, the new values shall become the approved reference Charpy values;
- supervise the test specified in 9.2.5 (flawed cylinder burst test) for cylinders with wall thickness < 3 mm where no impact tests are required. This test shall be carried out on 1 cylinder per cast or, if the cast exceeds 1 000 cylinders, 1 cylinder per 1 000 cylinders or part thereof;
- check that the information supplied by the manufacturer referred to in 10.1.1 is correct; random checks shall be carried out;
- assess the results of hardness testing referred to in 11.3.

NOTE Consideration should be given to selecting cylinders representing the lower and upper values of the hardness range within the batch.

The following tests shall be carried out on each batch of cylinders:

- a) On one cylinder:
 - one hydraulic bursting test (see 10.5).
- b) On a further cylinder:
 - one tensile test in the longitudinal direction (see 10.2);
 - either two bend tests (see 10.3.1) in a circumferential direction or one flattening test (see 10.3.2) or one ring flattening test (see 10.3.3);
 - three impact tests in transverse or longitudinal direction as required in 10.4 when the thickness of the cylinder permits the machining of a test piece at least 3 mm thick.

For location of test pieces, see Figure 6.

Impact and tensile test specimens may be taken from the cylinder used for the burst test (10.5) or the cylinder used for the flattening test (10.3.2). Bend or ring flattening test pieces may be taken from the burst tested cylinder. The location of the test specimen shall be chosen to avoid interference with the deformed parts of the cylinder.

- c) If necessary, on further cylinders:
 - one or two flawed cylinder burst tests, depending on the Charpy impact values obtained in the batch test.

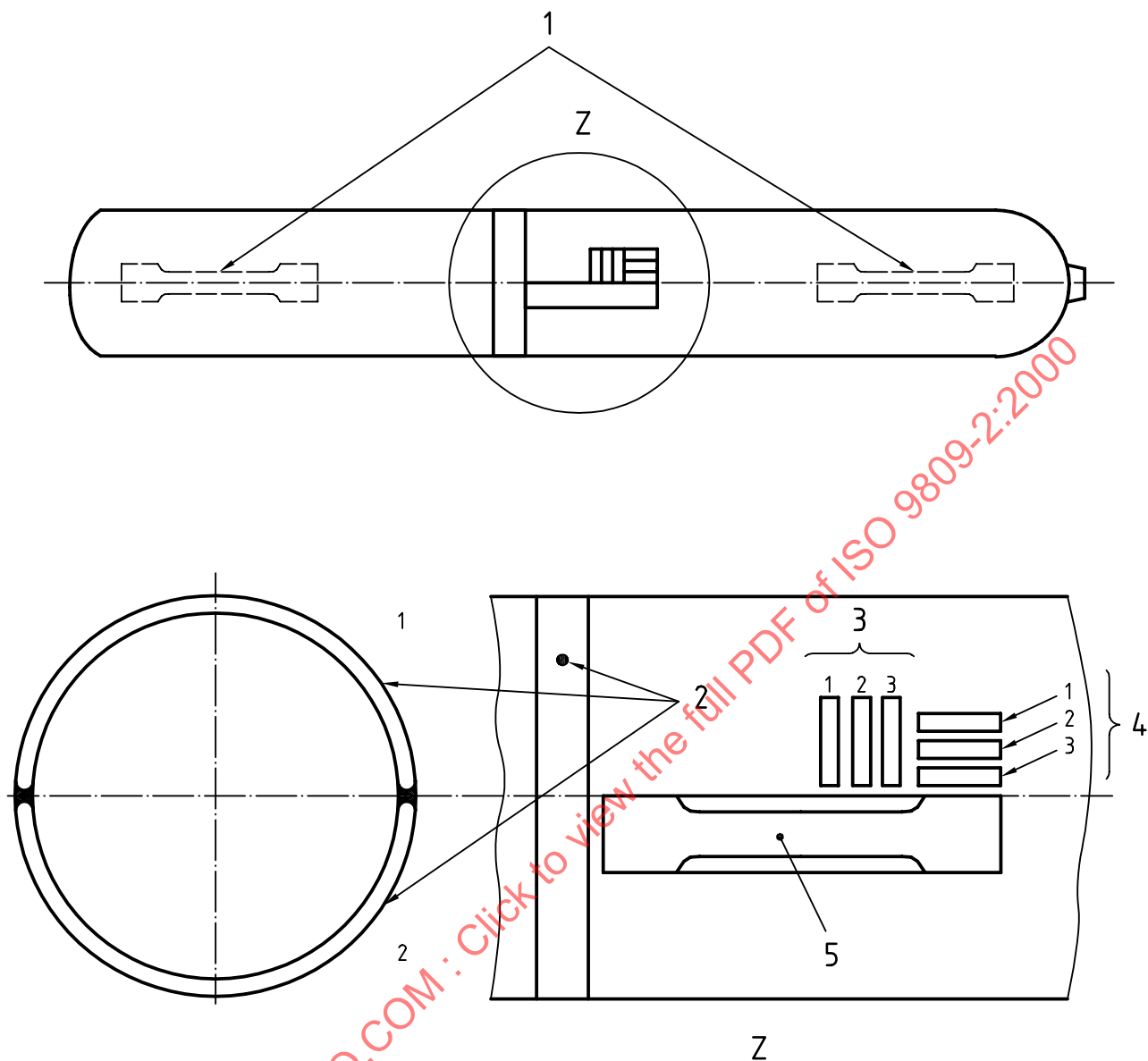
10.2 Tensile test

10.2.1 A tensile test shall be carried out on material taken from the cylindrical part of the cylinder by adopting either of the following procedures:

- a) Rectangular specimens shall be prepared in accordance with Figure 7 and with a gauge length $L_0 = 5,65\sqrt{S_0}$. The two faces of the test piece representing the inside and outside surfaces of the cylinder shall not be machined. The elongation, A , measured shall not be less than 12 %.
- b) Machined round specimens shall be prepared having the maximum diameter practicable, the elongation, A , measured on a gauge length of 5 times the specimen diameter being not less than 14 %. It is recommended that machined round specimens be not used for wall thickness less than 3 mm.

10.2.2 The tensile test shall be carried out in accordance with ISO 6892.

NOTE Attention is drawn to the method of measurement of elongation described in ISO 6892, particularly in cases where the tensile test piece is tapered, resulting in a point of fracture away from the middle of the gauge length.



Key

- 1 Hardness/tensile strength correlation tests (prototype tests only)

NOTE Dotted lines indicate that these tests are not required on every batch of cylinders but for prototype testing only.

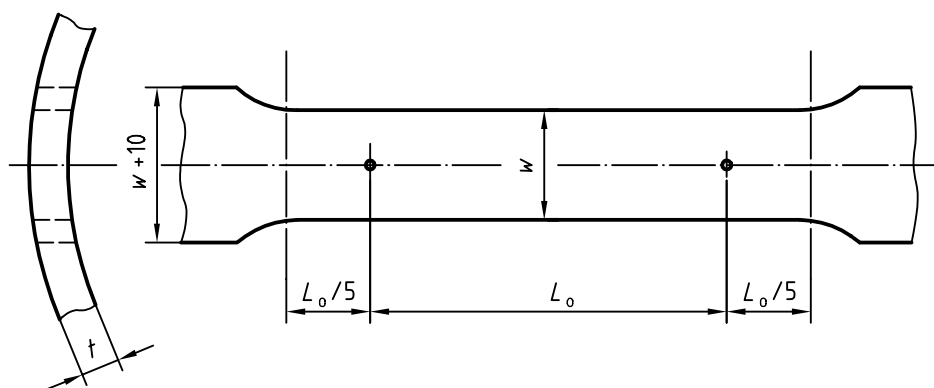
- 2 Bend test pieces or flattening ring test pieces

- 3 Transverse impact test pieces

- 4 Longitudinal impact test pieces

- 5 Tensile test piece

Figure 6 — Location of test pieces



$$w \leq 4t$$

$$w < D/8$$

Figure 7 — Tensile test piece

10.3 Bend test and flattening test

10.3.1 Bend test

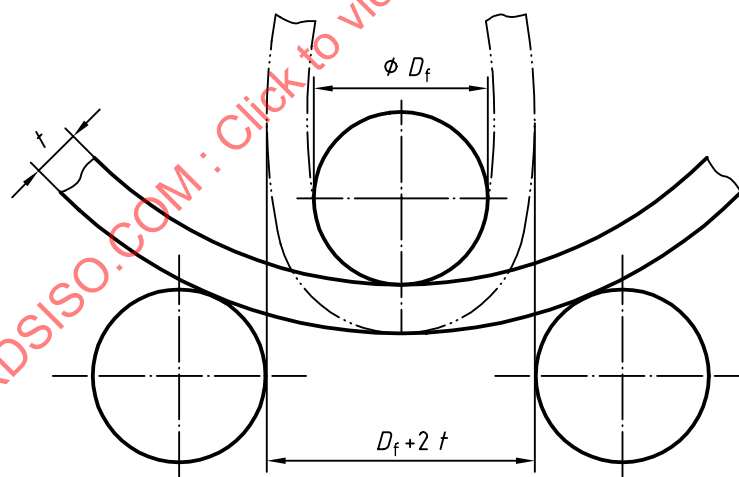


Figure 8 — Illustration of bend test

10.3.1.1 The bend test shall be carried out in accordance with ISO 7438 on two test pieces obtained by cutting either one or two rings of width 25 mm or $4t$, whichever is greater, into equal parts. Each test piece shall be of sufficient length to permit the bend test to be carried out correctly. Only the edges of each strip may be machined.

10.3.1.2 The test piece shall not crack when bent inwards around the former until the inside surfaces are no further apart than the diameter of the former (see Figure 8).

10.3.1.3 The diameter of the former, D_f , shall be 8 times the actual wall thickness of the test piece t .

10.3.2 Flattening test

10.3.2.1 The flattening test shall be performed on one cylinder selected from each batch after heat treatment.

10.3.2.2 The test cylinder shall be flattened between wedge-shaped knife edges with a 60° included angle, the edges being rounded to a nominal radius of 13 mm. The length of the wedges shall not be less than the width of the flattened cylinder. The longitudinal axis of the cylinder shall be at an angle of approximately 90° to the knife edges.

10.3.2.3 The test cylinder shall be flattened until the distance between the knife edges is $10 t_m$, where t_m is the average cylinder wall thickness at the position of testing. The flattened cylinder shall remain visually uncracked.

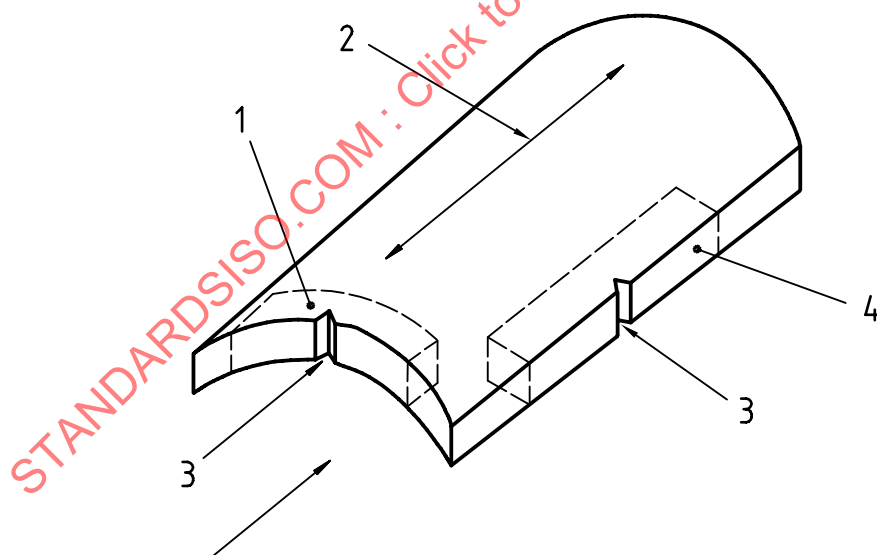
10.3.3 Ring flattening test

The ring flattening test shall be carried out on one ring of width 25 mm or $4t$, whichever is the greater, taken from the cylinder body. Only the edges of the ring may be machined. The ring shall be flattened between platens until the distance between platens is 10 times the average thickness of the test ring. The flattened ring shall remain visually uncracked.

10.4 Impact test

10.4.1 Except for the requirements set out below, the test shall be carried out in accordance with ISO 148.

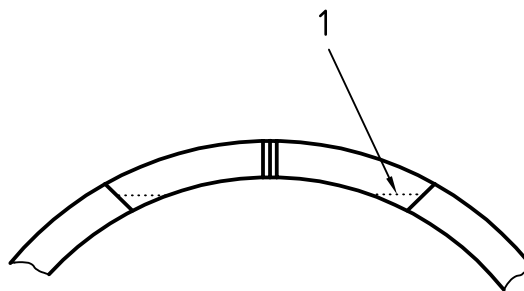
The impact test pieces shall be taken in the direction as required in Table 4 from the wall of the cylinder. The notch shall be perpendicular to the face of the cylinder wall (see Figure 9). For longitudinal tests the test piece shall be machined all over (on six faces). If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the cylinder wall. The test pieces taken in the transverse direction shall be machined on four faces only, the outer face of the cylinder wall unmachined and the inner face optionally machined as shown in Figure 10.



Key

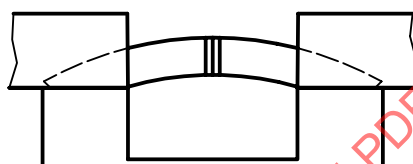
- 1 Transverse specimen
- 2 Cylinder longitudinal axis
- 3 Charpy V-notch perpendicular to wall
- 4 Longitudinal specimen

Figure 9 — Description of transverse and longitudinal impact test pieces

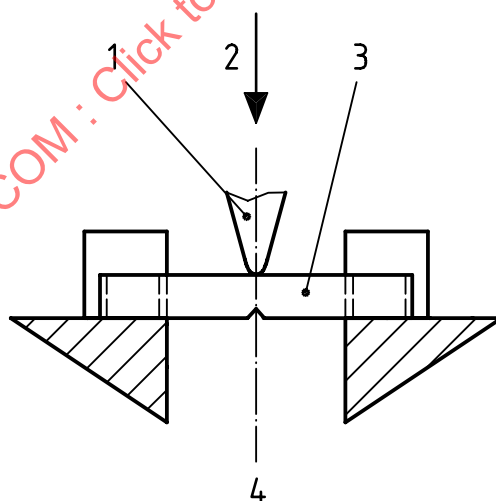
**Key**

- 1 Machining optional

a) Test piece taken from cylinder wall



b) Front view of test piece in impact tester

**Key**

- 1 Striking anvil
2 Direction of strike
3 Test piece
4 Centre of strike

c) Top view of test piece in impact tester

Figure 10 — Description of transverse impact testing

10.4.2 Minimum acceptance values are given in Table 4.

Table 4 — Impact test acceptance values

Cylinder diameter, D , mm			> 140			≤ 140
Direction of testing			transverse			longitudinal
Minimum wall thickness, mm			3 to 5	> 5 to 7,5	> 7,5 to 12	3 to 5
Test temperature ^a , °C			-50			-50
Impact strength, J/cm ²	Mean of three	A ^c	30	35	40	60
	specimens ^b	B ^d	40	50	60	60

^a Pour For applications at lower temperatures the test shall be carried out at the lowest temperature specified.

^b No individual value shall be less than 70 % of the mean value.

^c A-values: absolute minimum acceptance values (average of 3 specimens).

^d B-values: mean values above which no flawed burst test is required as a batch test (see 10.1.2).

10.5 Hydraulic bursting test

10.5.1 Test installation

The test equipment shall be capable of operation in accordance with the test conditions specified in 10.5.2 and of producing accurately the information required by 10.5.3.

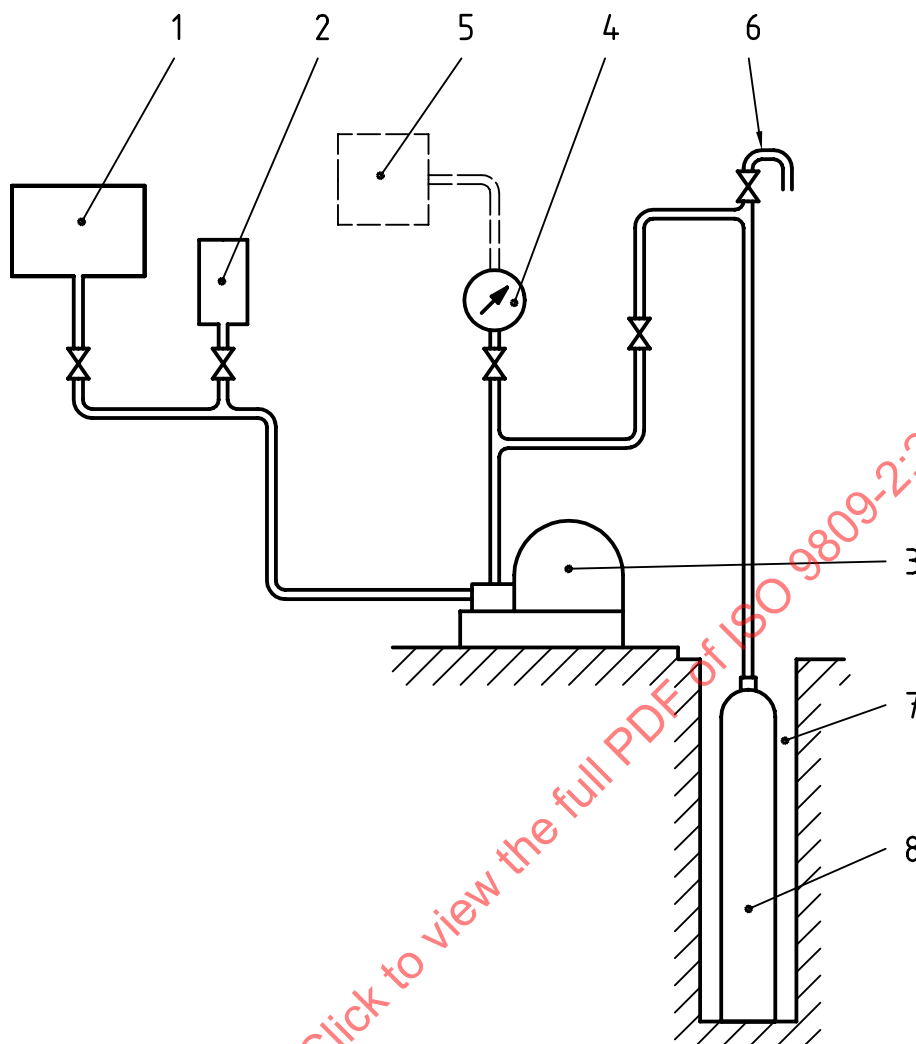
A typical hydraulic bursting test installation is illustrated in Figure 11.

10.5.2 Test conditions

As the cylinder and test equipment are being filled with water, care shall be taken to ensure that no air is trapped in the circuit by operating the hydraulic pump until water is discharged from the vent or air-release valve.

During the test, pressurization shall be carried out in two successive stages.

- In the first stage, the pressure shall be increased at a rate of not more than 5 bar/s up to a pressure value corresponding to the initiation of plastic deformation.
- In the second stage, the pump discharge rate shall be maintained at as constant a level as is possible until the cylinder bursts.

**Key**

- 1 Test fluid reservoir
- 2 Tank for measurement of test fluid (the feed tank may also be used as the measuring tank)
- 3 Pump
- 4 Pressure gauge
- 5 Pressure/time curve recorder
- 6 Vent or air release valve
- 7 Test well
- 8 Cylinder

Figure 11 — Typical hydraulic bursting test installation

10.5.3 Interpretation of test

10.5.3.1 Interpretation of the burst test shall involve:

- a) examination of the pressure/time curve or pressure/volume-of-water-used curve, to permit determination of the pressure at which plastic deformation of the cylinder commences, together with the bursting pressure;
- b) examination of the burst tear and of the shape of its edges.

10.5.3.2 For the results of a bursting test to be considered satisfactory, the following requirements shall be met.

- a) The observed yield pressure, p_y , shall be $\geq \frac{1}{F} \times$ the test pressure; i.e. $p_y \geq \frac{1}{F} \times p_h$
- b) The actual burst pressure, p_b , $\geq 1,6 \times$ the test pressure; i.e. $p_b \geq 1,6 p_h$

10.5.3.3 The cylinder shall remain in one piece and shall not fragment.

10.5.3.4 The main fracture shall be in the cylindrical portion and shall not be brittle, i.e. the fracture edges shall be inclined with respect to the wall. The tear shall not reveal a significant defect in the metal.

10.5.3.5 For cylinders with a guaranteed minimum wall thickness (a') less than 7,5 mm, the fracture shall be acceptable only if it conforms to one of the following descriptions:

- a) longitudinal, without branching (see Figure 12);
- b) longitudinal, with a side branching at each end which in no case exceeds 1/3 of the cylinder circumference (see Figure 13).

10.5.3.6 Acceptance criteria

Figure 12 and Figure 13 illustrate satisfactory burst test profiles, and batches represented by such results shall be accepted.

If the configuration of the fracture does not conform to Figure 12 or to Figure 13, but all other material and mechanical tests are satisfactory, investigation of the cause of the non conformity shall be undertaken prior to acceptance or rejection of the batch.

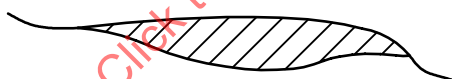


Figure 12 — Acceptable burst profiles— Longitudinal without branching

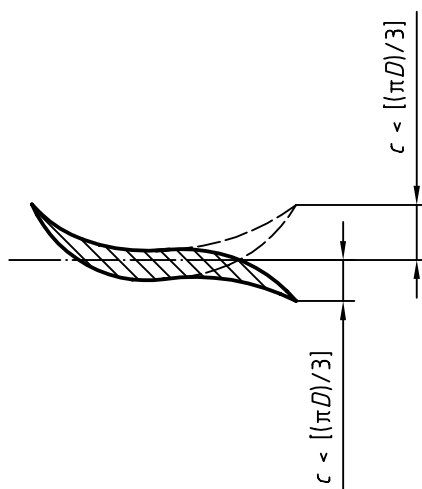


Figure 13 — Acceptable burst profiles — Longitudinal with branching

11 Tests on every cylinder

11.1 General

During production the tests as required in 8.2 and 8.4 shall be carried out on all cylinders.

Following heat treatment, all cylinders except those selected for testing under clause 10, shall be subjected to the following tests:

- a hydraulic proof pressure test in accordance with 11.2.1 or a hydraulic volumetric expansion test in accordance with 11.2.2. The purchaser and manufacturer shall agree which of these alternatives shall be carried out;
- a hardness test in accordance with 11.3;
- a leak test in accordance with 11.4.

11.2 Hydraulic test

11.2.1 Proof pressure test

The water pressure in the cylinder shall be increased at a controlled rate until the test pressure, p_h , is reached.

The cylinder shall remain under pressure p_h for at least 30 s to establish that the pressure does not fall and that there are no leaks.

11.2.2 Volumetric expansion test

The water pressure in the cylinder shall be increased at a controlled rate until the test pressure, p_h , is reached.

The cylinder shall remain under pressure p_h for at least 30 s and the total volumetric expansion measured. The pressure shall then be released and the volumetric expansion remeasured.

The cylinder shall be rejected if it shows any permanent expansion (i.e. volumetric expansion after the pressure has been released) in excess of 5 % of the total volumetric expansion measured at the test pressure, p_h .

The total and permanent expansion readings shall be recorded together with the corresponding serial number of each cylinder tested, so that the elastic expansion (i.e. total expansion less permanent expansion) under the test pressure can be established for each cylinder.

11.3 Hardness test

A hardness test in accordance with ISO 6506 (Brinell), ISO 6508 (Rockwell) or other equivalent methods shall be carried out at each end of every cylinder by the manufacturer after the final heat treatment and the values recorded. The hardness values thus determined shall be within the limits established during prototype testing (see 9.2.3).

NOTE Methods for measuring the surface indentations, other than those given in ISO 6506 or ISO 6508 may be used subject to agreement between the parties concerned.

11.4 Leak test

The manufacturer shall employ such manufacturing techniques and apply such tests as will demonstrate to the satisfaction of the inspector that the cylinders do not leak.

12 Certification

Each batch of cylinders shall be covered by a certificate signed by the inspecting authority's representative to the effect that the cylinders meet the requirements of this part of ISO 9809 in all respects. An example of a suitably worded certificate is given in annex D.

Copies of the certificate shall be issued to the manufacturer. The original of the certificate shall be retained by the inspector and the copies by the manufacturer in accordance with the regulations of the relevant statutory authority.

13 Marking

Each cylinder shall be stamped on the shoulder or on a reinforced part of the cylinder or on a permanently fixed collar or neck ring in accordance with ISO 13769 or the relevant marking requirements of the countries of use.

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Annex A

(informative)

Evaluation of manufacturing defects and conditions for rejection of seamless steel gas cylinders at time of final visual inspection by the manufacturer

A.1 Introduction

Several types of defects can occur during the manufacturing of a seamless steel gas cylinder.

Such defects can be mechanical or material. They can be due to the basic material used, the manufacturing process, heat treatments, manipulations, necking, machining or marking operations and other circumstances during manufacturing.

The aim of this annex is to identify the manufacturing defects most commonly met and to provide general guidelines to the inspectors that perform the visual inspection. Nevertheless extensive field experience, good judgement and independence from production are necessary on the part of the inspector to be able to detect and to evaluate and judge a defect at the time of the visual inspection.

A.2 General

A.2.1 It is essential to perform the visual internal and external inspection under good conditions.

- The surface of the metal and in particular of the inner wall shall be completely clean, dry and free from oxidation products, corrosion, scale etc., since these could obscure other more serious defects. Where necessary, the surface should be cleaned under closely controlled conditions by suitable methods before further inspection.
- Appropriate sources of illumination with sufficient intensity should be used.
- After the cylinders have been closed and the threads have been cut, the internal neck area should be examined by means of an introscope, dental mirror or other suitable appliance.

A.2.2 Small defects may be removed by local dressing, grinding, machining or other appropriate methods.

Great care should be taken to avoid introducing new injurious defects.

After such a repair the cylinders should be re-examined.

A.3 Manufacturing defects

The most commonly found manufacturing defects and their definitions are listed in Table A.1.

Rejection limits for repair or reject are also included in Table A.1. These rejection limits are established following considerable field experience. They apply to all sizes and types of cylinders and service conditions. Nevertheless some customer specifications, some types of cylinders or some special service conditions may require more stringent conditions.

A.4 Rejected cylinders

- a) All rejected cylinders should be rendered unserviceable for their original application.
- b) It may be possible to produce cylinders for different service conditions from rejected cylinders.

Table A.1 — Manufacturing defects

Defect	Description	Conditions for rejection and/or actions	Repair/Reject
Bulge	Visible swelling of the wall	All cylinders with such a defect	Reject
Dent (flats)	A depression in the wall that has neither penetrated nor removed metal (see Figure A.1) (see also excessive grinding or machining)	– when the depth of the dent, h_{dent}, exceeds 2 % of the external diameter of the cylinder – when the depth of the dent h_{dent} is greater than 1 mm and when the diameter of the dent, ϕ, is less than 30 times its depth ^a	Reject Permit repair
Cut, gouge, metallic or scale impression	An impression in the wall where metal has been removed or redistributed (due basically to the introduction of foreign bodies on the mandrel or matrix during extrusion or drawing operations)	– <u>inside defect</u>: if not superficial with sharp notches more than 5 % of wall thickness ^b – <u>outside defect</u>: when the depth exceeds 5 % of the wall thickness of the cylinders	Repair Repair possible (see A.2.2)
Dent, containing cut or gouge	A depression in the wall which contains a cut or gouge (see Figure A.2)	All cylinders with such defects	Reject
Excessive grinding or machining	Local reduction of wall thickness by grinding or machining	– when the wall thickness is reduced to below the minimum design thickness. – when it results in the formation of a dent.	Reject see "dent" above
Rib	A longitudinal raised surface with sharp corners (see Figure A.3)	– <u>inside defect</u> : if height or depth exceeds 5 % of wall thickness or if the length exceeds 10 % of the length of the cylinders.	Repair if possible or reject
Groove	A longitudinal notch (see Figure A.4)	– <u>outside defect</u> : when the height or depth exceeds 5 % of the wall thickness or when the length exceeds 5 times the thickness of the cylinders.	Repair if possible or reject (see A.2.2)
Lamination	Layering of the material within the cylinder wall and sometimes appearing as a discontinuity, crack, lap or bulge at the surface (see Figure A.5)	– <u>inside defect</u>: all cylinders with such defect – <u>outside defect</u>: all cylinders with such defect	Repair if possible or reject Repair if possible or reject (see A.2.2)
Crack	Split, material separation	– when not removable within thickness tolerance – when removable within thickness tolerance	Reject Repair
Neck cracks	Appear as lines which run vertically down the thread and across the thread faces. (They should not be confused with tap marks i.e. Thread machining marks) (see Figure A.6)	All cylinders with such defects	Reject

Table A.1 (continued)

Defect	Description	Conditions for rejection and/or actions	Repair/Reject
Shoulder folds and/or shoulder cracks	Folding with peaks and troughs situated in the internal shoulder area, which can propagate into the threaded area of the shoulder (see Figure A.7). Cracks can start from folds in the internal shoulder area and propagate into the cylindrical machined or threaded area of the shoulder. (Figure A.8 shows exactly where shoulder cracks start and how they propagate.)	– folds or cracks that are visible as a line of oxide running into the threaded portion should be removed by a machining operation until the lines of oxide are no longer visible (see Figure A.7). After machining, the whole area should be re-inspected carefully and the wall thickness verified. – if folding or lines of oxide have not been removed by machining or if cracks are always visible or if wall thickness is unsatisfactory – folds which extend beyond the machined area and are clearly visible as open depressions where no oxides have been trapped in the metal, should be accepted provided that the peaks are smooth and the root of the depression is rounded.	Repair if possible Reject Acceptable
Internal cracks in base	Splits in the metal of the bottom of the cylinder in star form.	– when not removable within thickness tolerance – when removable within thickness tolerance	Reject Repair
“Orange peel” surface	Orange peel appearance due to discontinuous metal flow.	If sharp cracks are visible in the orange peel surface	Repair if possible or reject
Internal neck threads damaged or out of tolerance	Neck threads damaged, with dents, cuts, burrs or out of tolerance.	– when the design permits it, threads may be re-tapped and re-checked by the appropriate thread gauge and carefully visually re-examined. The appropriate number of effective threads shall be guaranteed. – if not repairable	Repair Reject
Pitting	Severe surface corrosion.	All cylinders with such defects visible after shot blasting	Reject
Non conformity with design drawing		All cylinders presenting such a defect	Repair if possible or reject
Neck ring not secure	Neck ring turns under application of low torque or pulls off under low axial load. See ISO 11117 for guidance.	All cylinders presenting such a defect	Repair possible according to approved method only
Arc or torch burns	Partial burning of the cylinder metal, the addition of weld metal or the removal of metal by scarfing or cratering.	All cylinders presenting such a defect	Reject

^a On small diameter containers these general limits may have to be adjusted. Consideration of appearance also plays a part in the evaluation of dents, especially in the case of small cylinders.

^b Consideration of appearance and localization (in thicker parts with lower stresses) can be taken into account.

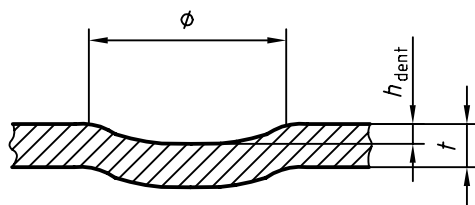


Figure A.1 — Dent

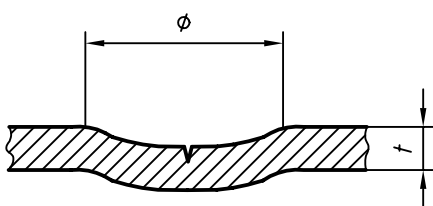


Figure A.2 — Dent containing cut or gouge

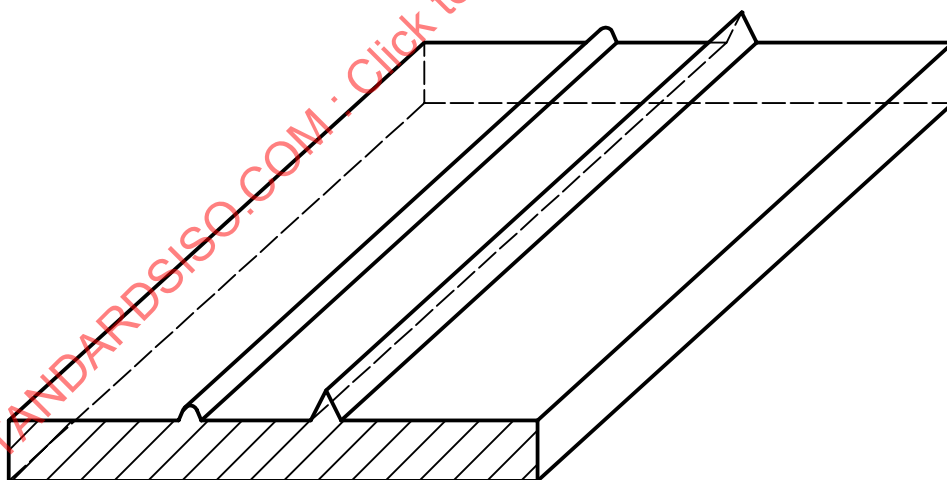


Figure A.3 — Rib

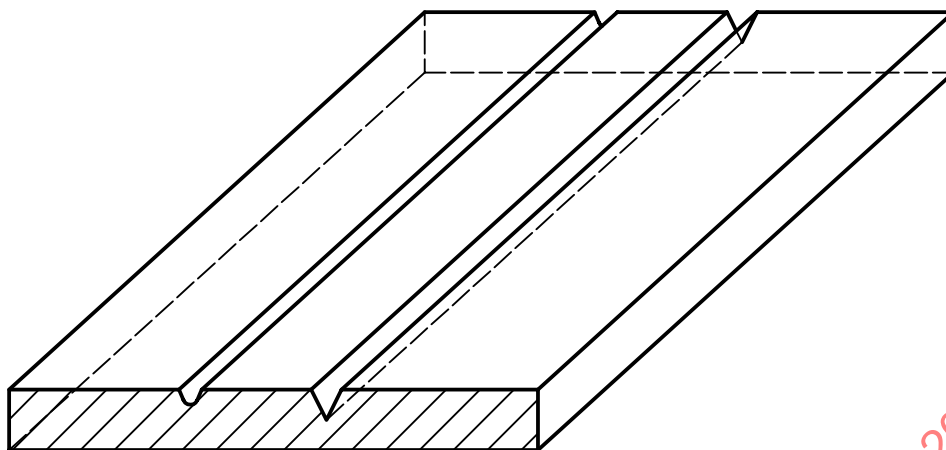
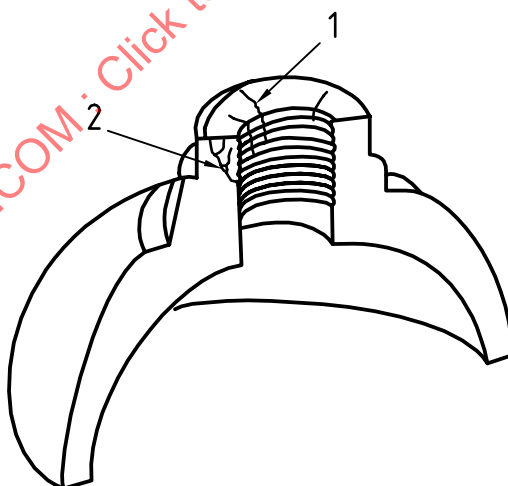


Figure A.4 — Groove



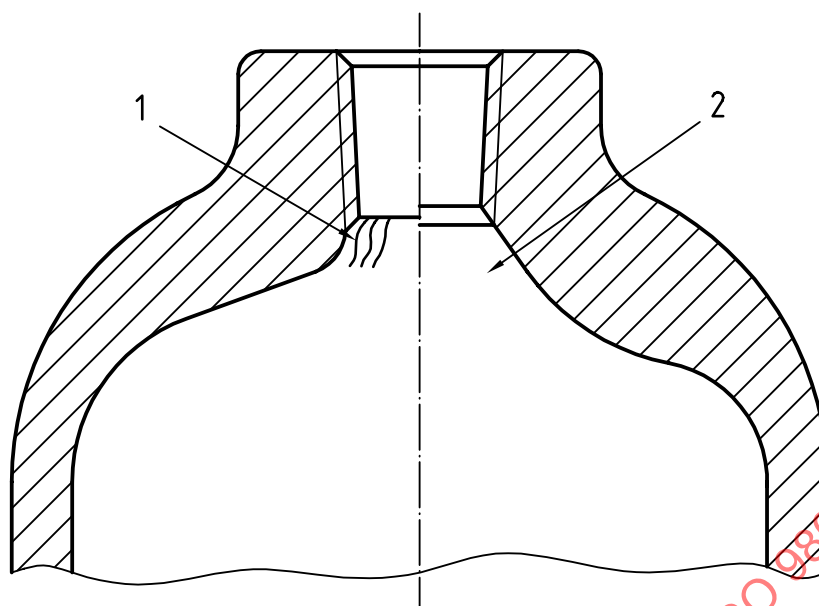
Figure A.5 — Lamination



Key

- 1 Neck cracks
- 2 Propagated neck cracks

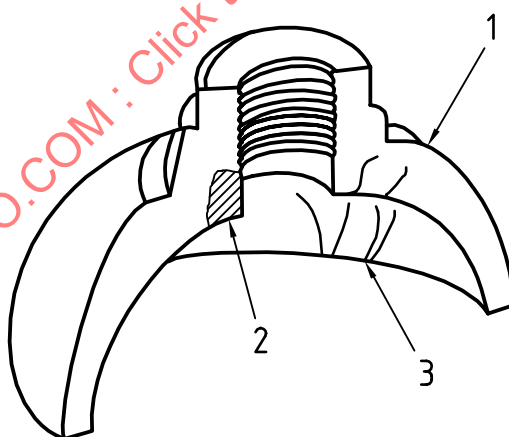
Figure A.6 — Neck cracks



Key

- 1 Folds or cracks
- 2 After machining

Figure A.7 — Cylinder shoulder folds or cracks before and after machining



Key

- 1 Shoulder cracks
- 2 Propagated shoulder cracks
- 3 Fold

Figure A.8 — Shoulder cracks